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FREEZING INJURY TO BELL PEPPERS

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FREEZING INJURY TO BELL PEPPERS

By C. S. PARSONS, *research horticulturist*, and R. H. DAY, *agricultural research technician*,
Market Quality Research Division, Agricultural Research Service

SUMMARY

Freezing injury symptoms are described for bell peppers (*Capsicum annuum* L.) that were frozen in air at 0° or 20° F. for one-half, 1, 2, or 4 hours and subsequently held at 40° or 70° for 1 day or 1 week.

On removal from the freezing temperatures to 40° or 70° F., the only sign of freezing injury is dead, water-soaked tissue in part of or all the pericarp surface. After thawing, the water-soaked tissue is soft and flabby in texture and exudes juice when cut. The affected areas do not enlarge during or after thawing.

During holding at 40° or 70° F. injured areas of

the pepper shrivel, or when the areas are small, they become pitted. In some peppers with severe freezing injury the stem and stem cap discolor during holding. After 1 week at 70° all lots with freezing injury have an appreciable number of peppers with moderate to severe decay. After 1 week at 40° only lots frozen 4 hours at 0° have an appreciable number with decay.

Salability of fresh bell peppers rapidly decreases as the extent of freezing injury increases. Slightly injured peppers remain salable for 1 week when stored at 40° F. but are salable for only 1 day when kept at 70°.

INTRODUCTION

Fresh fruits and vegetables that have been injured by freezing are usually more susceptible to decay, inferior in quality, and poorer in appearance than those that have not been frozen. However, when the frozen produce is handled properly, the damage and loss by freezing can often be partly or entirely eliminated. Understanding the nature of freezing and prompt and accurate identification of freezing injury are essential before proper handling practices can be employed.

Symptoms of freezing injury in peppers examined immediately after thawing have been described by Lauritzen and Wright,¹ Ramsey

and Link,² and Rose et al.³ In their studies no comparisons were made of the effects of different freezing temperatures or of different thawing and holding temperatures on injury to peppers.

The purpose of this study is to identify, describe, and illustrate the symptoms of freezing injury in bell peppers and to determine the effects of rapid and slow freezing and thawing on the overall quality of peppers.

² RAMSEY, G. B., and LINK, G. K. K. MARKET DISEASES OF FRUITS AND VEGETABLES: TOMATOES, PEPPERS, EGGPLANTS. U.S. Dept. Agr. Misc. Pub. 121, 44 pp. 1932.

³ ROSE, D. H., WRIGHT, R. C., and BRATLEY, C. O. FREEZING INJURY OF FRUITS AND VEGETABLES. U.S. Dept. Agr. Cir. 713, 31 pp. 1944.

¹ LAURITZEN, J. I., and WRIGHT, R. C. SOME CONDITIONS AFFECTING THE STORAGE OF PEPPERS. Jour. Agr. Res. 41 (4): 295-305. 1930.

MATERIALS AND METHODS

Eight lots of fresh California Wonder bell peppers (*Capsicum annuum* L.) were purchased at the Washington, D.C., wholesale market. Each lot contained from 150 to 200 peppers. At the Beltsville, Md., laboratories of the U.S. Department of Agriculture each lot was carefully examined and all defective peppers were discarded.

Fifteen sound peppers were taken at random from each lot to study ice crystal formation. Ten of these peppers were used to determine the time required for ice crystals to form in pods (peppers) held without jarring in air at 0° or 20° F. A copper-constantan thermocouple was inserted one-eighth to one-fourth inch into the

shoulder of each pepper. Electrical signals generated by the thermocouple were fed to a 1-mv. potentiometric strip-chart recorder with a 32° ice water reference junction. At 32° the zero potential of a copper-constantan thermocouple is zero. By raising this zero point to read 50 on the 0 to 100 recorder scale, temperatures ranging from 8.4° to 55° were continuously recorded. In each pepper the changing temperature at the point at which the thermocouple was inserted was recorded until after ice crystals formed. The time of inoculation or start of ice formation was indicated on the recorder chart by a sharp rise in temperature caused by the heat of fusion liberated when the ice crystals formed (fig. 1).

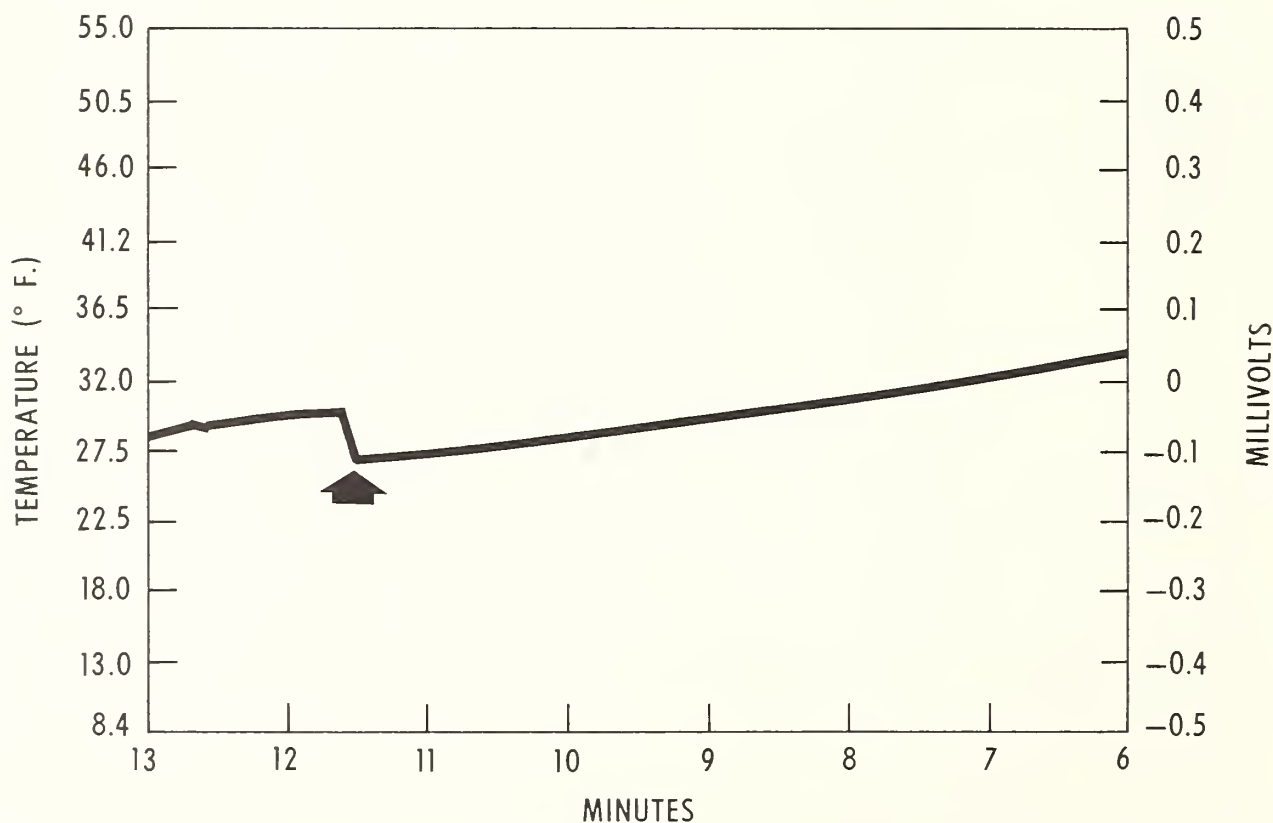


FIGURE 1.—Point of ice crystal formation (arrow) in pepper held at 0° F. Chart moves from left to right. (This is copy of actual machine-made chart.)

The remaining five of the randomly selected peppers were used to study the effect of motion or jarring on ice crystal formation. Peppers with thermocouples inserted were placed in the 0° and 20° F. freezers on an electric vibrator, which continuously vibrated the peppers at 120 c.p.s. Temperatures in these peppers were also continuously recorded until about 2 minutes after ice crystals had formed.

The remaining peppers in each lot were divided into 10 equal-size samples and placed at 45° F. overnight. Each sample consisted of from 12 to 16 peppers. The data for frozen and nonfrozen peppers in the tables are the averages of 55 and 110 peppers, respectively. Eight of the 10 samples in each lot were frozen in 21-cubic-foot chest-type freezers at 0° or 20°. Special thermostats installed in each freezer controlled the tempera-

ture within $\pm 1^\circ$ of 0° or 20°. One sample, respectively, was in each freezer for one-half, 1, 2, and 4 hours after the start of ice crystal formation. The individual samples of peppers were placed in the freezers at predetermined intervals so that all could be removed simultaneously.

At removal all peppers were examined externally and some were cut and examined internally. The remainder in each sample was divided into two subsamples, one of which was placed in a room held at 40° F. and the other in a room at 70°. The relative humidity ranged between 85 and 90 percent. A single unfrozen sample placed in each room served as a check. All peppers were reexamined externally after 1 day or 1 week at 40° or at 70°. Samples were photographed to show freezing injury.

RESULTS AND DISCUSSION

Ice Crystal Formation

Many fruits and vegetables may be cooled to temperatures considerably below their freezing points before ice crystals form within their tissues. This phenomenon of undercooling or supercooling occurs only when the commodity is held motionless. The slightest jar or movement causes ice crystals to form instantly if the commodity temperature is at or below the freezing point.

Peppers held without observable motion or jarring in air at 0° F. continued cooling for 12 minutes after the flesh temperature had reached 32°, and the flesh temperature dropped below 20° before inoculation or ice crystal formation (fig. 2). Immediately after the ice crystals formed, the temperature of the pepper in the area of the thermocouple rose to 30.3°. This corresponds rather closely to the 30.5° freezing point of peppers reported by Whiteman.⁴ The increase in temperature at the instant that ice formed in the pepper was due, of course, to the heat of fusion liberated when a liquid changes to a solid.

When peppers at 0° F. were continuously vibrated, ice crystals formed about 1½ minutes

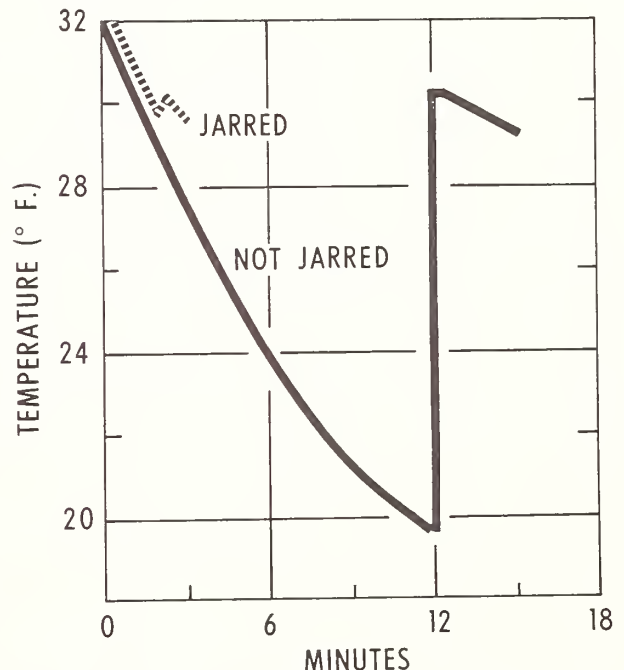


FIGURE 2.—Effect of jarring on undercooling and ice formation in peppers held at 0° F.

⁴ WHITEMAN, T. M. FREEZING POINTS OF FRUITS, VEGETABLES, AND FLORIST STOCKS. U.S. Dept. Agr. Mktg. Res. Rpt. 196, 32 pp. 1957.

after the flesh temperature had reached 32°. At this point the peppers had undercooled to only 29.4°. Immediately after inoculation the temperature in the area of the thermocouple also rose to 30.3°.

The time required for ice crystals to form in peppers and the amount of subsequent freezing injury are determined to a great extent by the temperature at which the freezing takes place. When peppers were held without observable motion at 0° F., ice crystals formed in only 12 minutes after the pods had reached 32° (fig. 3). When they were held at 20°, ice crystals formed in 28 minutes. Peppers kept at 0° were undercooled to about 20° before ice crystals formed. At 20° the formation occurred at about 24°.

Freezing injury occurs in fruits and vegetables only after ice crystals form within the tissues. To prevent ice formation, extreme care should be exercised in handling produce after it has been cooled to temperatures near or below the freezing point.

Symptoms of Freezing Injury

Water-soaking

Immediately on removal from 0° or 20° F. the only external sign of injury in frozen or partly frozen peppers was the dead or water-soaked appearance of some tissues (fig. 4). On thawing, the tissues were soft, watery, and flabby in texture in contrast to the firm and brittle tissues of an uninjured pepper. The external color of a pepper injured by freezing was darker than normal and the stems were sometimes softer than those of nonfrozen peppers.

The degree or severity of water-soaking in peppers injured by freezing depends on the length of exposure to the freezing temperature and to the temperature itself. When held at 20° F. for one-half hour, water-soaking appeared in about 4 percent of the peppers and was confined to the shoulders of the pods (table 1). When held at 0° for the same period, about 40 percent of the peppers were water-soaked. All peppers were

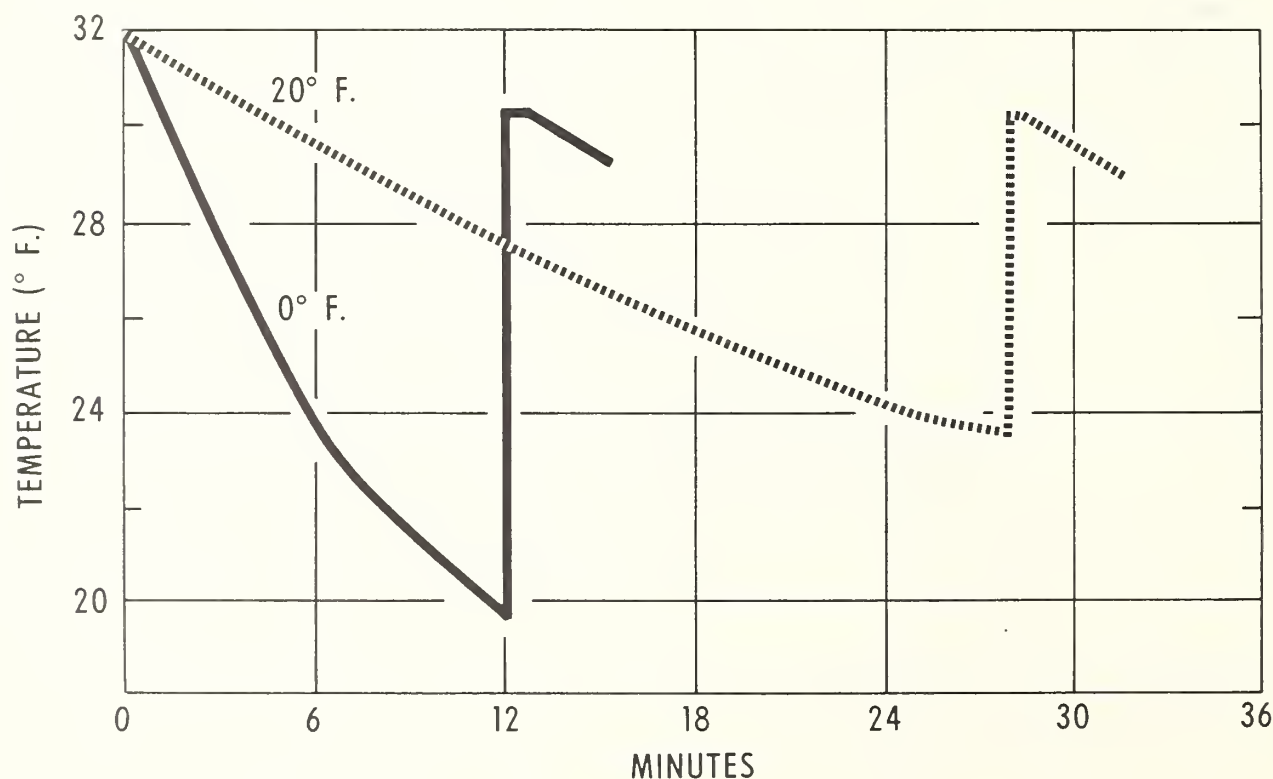
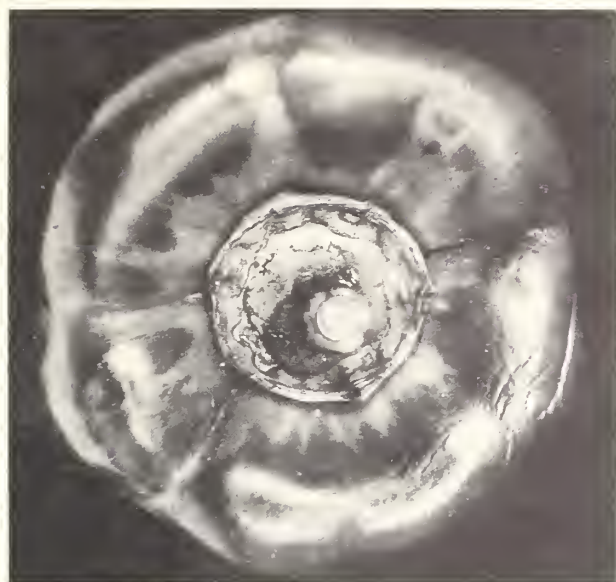


FIGURE 3.—Ice formation in peppers held without jarring at 0° and 20° F.



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FIGURE 4.—Water-soaking injury on shoulders of pepper after one-half hour at 0° F.

completely water-soaked when held 2 hours or longer at 0°. At 20° about two-thirds of the peppers had some water-soaking after 2 hours and about 90 percent after 4 hours.

Thawing and holding peppers, injured by freezing, at 40° or 70° F. had no significant effect on the severity of water-soaking, nor did water-soaked areas enlarge during holding at these temperatures. In almost all samples, water-soaking appeared in tissues during freezing or subsequent thawing and remained until the peppers were discarded 1 week after removal from 0° or 20°. In a few instances small areas of water-soaked tissue, which were apparent immediately after freezing, were not discernible after 1 week at 40° or 70°. The water-soaking was masked by pitting or shriveling.

Internal water-soaking was seen after cutting peppers that had been held 1 hour or longer at 0° F. and those held 2 hours or longer at 20°. When these peppers were cut horizontally, fluid

TABLE 1.—*Extent of various freezing injury symptoms in peppers held at 0° and 20° F. and then stored for 1 day or 1 week at 40° or 70°*

Freezing temperature (° F.) and duration	Extent of symptom after—			
	1 day 40°	1 day 70°	1 week 40°	1 week 70°
	Percent	Percent	Percent	Percent
WATER-SOAKING				
Nonfrozen (check) -----	0	0	0	0
Hours held at 0°:				
1/2-----	42	36	38	36
1-----	87	87	87	87
2-----	100	100	100	100
4-----	100	100	100	100
Hours held at 20°:				
1/2-----	5	2	5	2
1-----	7	5	7	5
2-----	65	60	65	58
4-----	94	89	94	89
SOFTENING				
Nonfrozen (check) -----	0	0	0	65
Hours held at 0°:				
1/2-----	2	5	0	69
1-----	40	38	38	73
2-----	100	100	100	100
4-----	100	100	100	100
Hours held at 20°:				
1/2-----	0	0	2	65
1-----	0	0	0	80
2-----	14	14	22	76
4-----	62	76	78	100

TABLE 1.—*Extent of various freezing injury symptoms in peppers held at 0° and 20° F. and then stored for 1 day or 1 week at 40° or 70°—Continued*

Freezing temperature (° F.) and duration	Extent of symptom after—			
	1 day 40°	1 day 70°	1 week 40°	1 week 70°
	Percent	Percent	Percent	Percent
PITTING				
Nonfrozen (check)	0	0	0	0
Hours held at 0°:				
½	2	51	27	62
1	0	2	7	16
2	0	0	0	0
4	0	0	0	0
Hours held at 20°:				
½	0	2	0	2
1	2	51	24	51
2	0	22	0	22
4	0	2	0	2
SHRIVELING				
Nonfrozen (check)	0	0	2	78
Hours held at 0°:				
½	18	18	51	76
1	38	56	54	80
2	94	100	100	100
4	100	100	100	100
Hours held at 20°:				
½	2	0	7	100
1	2	5	16	80
2	62	60	69	100
4	73	85	85	96
STEM AND STEM CAP DISCOLORATION				
Nonfrozen (check)	0	0	0	0
Hours held at 0°:				
½	0	0	0	0
1	16	16	16	16
2	58	51	62	51
4	92	100	100	100
Hours held at 20°:				
½	0	0	0	0
1	0	0	0	0
2	0	0	2	0
4	24	22	24	22
DECAY				
Nonfrozen (check)	0	0	2	18
Hours held at 0°:				
½	0	2	2	29
1	0	0	2	78
2	0	0	0	100
4	0	0	29	100
Hours held at 20°:				
½	0	2	2	24
1	2	0	2	34
2	0	2	2	67
4	0	0	0	91

exuded from the cut surface of the affected part of the outer wall (pericarp) and dripped freely when the tissue was squeezed. In addition, the surfaces were dark and water-soaked without the traces of white usually noted in the pericarp. Because of the increased drying at 70°, internal water-soaking was more difficult to discern in peppers held at this temperature than in those held at 40°, particularly when the freezing injury was slight.

The presence of brown seeds in peppers is not a dependable symptom of freezing injury. In these tests the greatest number of brown seeds was observed in peppers severely injured by freezing, but at one time or another some were observed in all peppers, including the nonfrozen checks. Dark-brown seeds in peppers often are caused by insect injury.

Softening

Peppers subjected to freezing temperatures tend to lose moisture and soften when thawed (table 1). The area of softened tissue is closely related to the freezing temperature and the duration of freezing to which the peppers are subjected. Softening in these tests was determined by hand pressure.

When peppers were held one-half or 1 hour at 20° F., they were only slightly injured. They did not soften in 1 day at either 40° or 70° or even in 1 week at 40°. After 1 week at 70°, however, from 65 to 80 percent of the pods were soft. When peppers were held more than 1 hour at 20°, some softening was noted after 1 day at 40° or 70°, and a high percentage of the peppers had softening after 1 week at these temperatures.

When peppers were kept only one-half hour at 0° F., they softened very little during 1 day at either 40° or 70° or during 1 week at 40°. After 1 week at 70°, however, 69 percent were soft. All peppers held 2 or 4 hours at 0° had some softened areas after 1 day at 40° and 70°.

When injured peppers were held only 1 day, the storage temperature of 40° or 70° F. in most tests had no real effect on the number of peppers that developed soft areas. When they were held 1 week, many more developed soft areas at 70° than at 40°.

Nonfrozen peppers did not soften when kept 1 day at either 40° or 70° or when held 1 week at

40° F. When held 1 week at 70°, almost two-thirds had soft areas due to moisture loss.

Pitting

Surface pitting often occurs following freezing, and the pits are sometimes found at abrasions or injuries produced by insects (fig. 5). Another type of pitting, sheet pitting, occurs at temperatures above freezing and has been described as a symptom of chilling injury by McCulloch.⁵ It was not observed in this study. Both types of pitting are apparently caused by water loss from injured areas.

Pitting was most severe after 1 day at 70° on peppers held one-half hour at 0° or 1 hour at 20° F. (table 1). More than 50 percent of these peppers were pitted. Moderate pitting was observed on

⁵ MCCOLLOCH, L. P. CHILLING INJURY AND ALTERNARIA ROT OF BELL PEPPERS. U.S. Dept. Agr. Mktg. Res. Rpt. 536, 16 pp. 1962.



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FIGURE 5.—Pitting on pepper held 2 hours at 20° F. and thawed 1 day at 70°.

peppers held 2 hours at 20° and a slight amount on those held one-half hour at 20°. Pitting was seldom seen on peppers severely injured by freezing, as these pods tended to lose water over their entire surface and not in localized or confined areas, which tend to produce pitting.

Pitting in peppers injured by freezing increased very little in severity during extended storage at 70° F. Most of it occurred during the first day after freezing, and only small increases were observed thereafter. At 40° only a few peppers held one-half hour at 0° or 1 hour at 20° were pitted after 1 day, but about one-fourth were pitted after 1 week.

Pitting was more severe in peppers stored at 70° than at 40° F. At the 1-day inspection 16 percent of all pods at 70° were pitted but less than 1 percent of those stored at 40° were pitted. After 1 week about 19 percent of the peppers at 70° were pitted as compared with 7 percent pitted at 40°.

Pitting was not observed in nonfrozen peppers held up to 1 week at 32°, 40°, or 70° F.

Shriveling

Peppers injured by freezing lose moisture and become shriveled when they thaw. The shriveling is observed initially on the shoulders of the pod, particularly if the pod has been injured only slightly. If the peppers are severely injured, the shriveling also occurs on the sides of the pods (fig. 6). The number of peppers that shrivel after injury by freezing will depend on the temperature and relative humidity at which they are thawed and the severity of the freezing conditions to which they are subjected.

Shriveling was more severe in peppers injured by freezing and held at 70° F. than in those held at 40° (table 1). The difference was only slight after 1 day but was pronounced after 1 week. For example, after 1 week 92 percent of all injured peppers stored at 70° were shriveled as compared with 60 percent shriveled at 40°. Nonfrozen peppers showed no shriveling after 1 day at 70° or 40°. But after 1 week 78 percent were shriveled at 70° and 2 percent at 40°.

Shriveling was usually more prevalent in peppers



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FIGURE 6.—Shriveling of peppers held 4 hours at 20° F. and thawed 1 day at 70°.

that had been frozen at 0° F. than in those that had been held for comparable periods at 20°. This was particularly true when the peppers were held at 40° after they had been injured by freezing. At 40° about 28 percent of the peppers that had been held one-half hour or 1 hour at 0° were shriveled after 1 day. In contrast, shriveling was observed in only 2 percent of those held for similar periods at 20°. After 1 week at 40° about 52 percent of the peppers kept at 0° were shriveled, whereas only 12 percent of those kept at 20° were affected.

Stem and stem cap discoloration

Severe freezing damage in peppers often appears as water-soaked and discolored stems and stem caps (fig. 7). The discoloration may be observed immediately after the peppers thaw, but it is usually seen more easily after holding the peppers 1 day at 40° or 70° F. Thawing and holding temperatures of 40° and 70° have little effect on the percentage of stems or caps that discolor; the percentage does not increase when peppers are held up to 1 week (table 1). Stems and caps of peppers held one-half, 1, or 2 hours at 20° showed almost no discoloration. However, when held 4 hours at 20°, about one-fourth had discolored stems or caps.

Stems and caps did not discolor in peppers held only one-half hour at 0° F. However, when held 1, 2, or 4 hours at 0°, the percentages of peppers with discolored stems and caps averaged 16, 54, and 96, respectively, after 1 day at 40° or 70°. Discolored stems or caps were not observed in

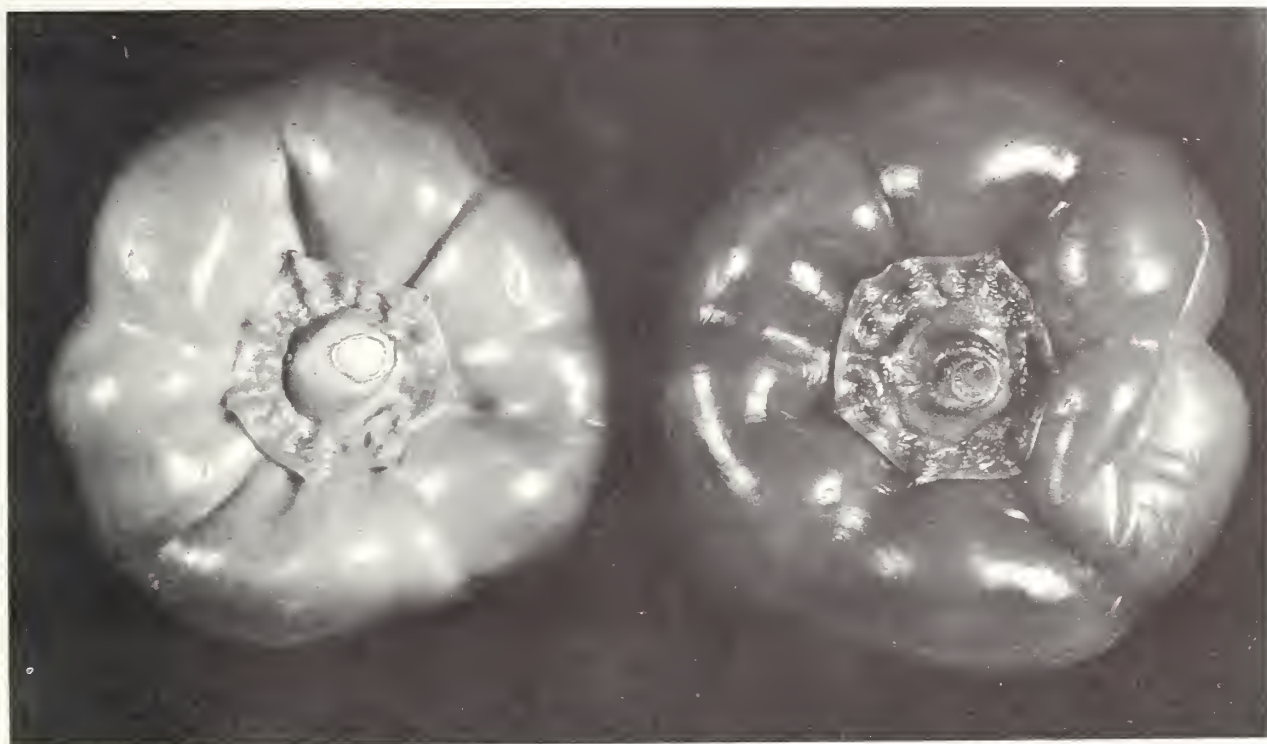
unfrozen peppers held 1 week at either 40° or 70°.

Decay

Decay affected few of the peppers that had been injured by freezing at 0° or 20° F. when they were subsequently held only 1 day at 40° or 70° (table 1). The small amount that occurred was often associated with abrasions, which were probably present on the peppers initially.

After 1 week at 40° F. only the peppers that had been held 4 hours at 0° were appreciably decayed; 29 percent of these were affected. Peppers in all other lots held at 0° or 20°, many of which were moderately or severely injured in other ways by the freezing, were only slightly affected by decay.

After 1 week at 70° F. decay had affected a high percentage of peppers in all lots that had been injured by holding at 0° or 20°. The percentages ranged from 24 of those held one-half



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FIGURE 7.—Appearance of stem and stem cap in nonfrozen pepper (left) and in pepper held 4 hours at 0° F. (right).

hour at 20° to 100 of those held 2 or 4 hours at 0°. Many of the latter had been reduced to mere shells by decay at the end of the week.

Nonfrozen peppers kept very well at 40° F. for 1 week, but 18 percent were decayed after 1 week at 70°.

Salability

The salability of peppers rapidly decreases as the severity of freezing injury increases (table 2). Peppers held one-half hour at 20° F. were 100 percent salable after thawing and holding 1 day at 40° or 70°. When the holding time at 20° was

extended to 1, 2, and 4 hours, salability dropped to an average of 88, 41, and 12 percent, respectively, after 1 day at 40° or 70°.

Freezing injury at 0° F. was more severe. The salability of peppers after 1 day at 40° or 70° dropped to about 75 percent after a ½-hour holding and to about 24 percent after a 1-hour holding at 0°. No peppers were salable after 2 or 4 hours' exposure to 0°.

Slightly injured peppers remained salable longer at 40° than at 70° F. Peppers held one-half hour at 20°, for example, were 100 percent salable after 1 day at 40° or 70°. After 1 week only 11 percent of these peppers were salable at 70°, but 96 percent were still salable at 40°.

TABLE 2.—*Salability of peppers injured by freezing at 0° and 20° F. and then stored for 1 day or 1 week at 40° or 70°*

Freezing temperature (° F.) and duration	Salability after—			
	1 day 40°	1 day 70°	1 week 40°	1 week 70°
	Percent	Percent	Percent	Percent
Nonfrozen (check)-----	100	100	94	14
Hours held at 0°:				
½-----	80	69	54	11
1-----	22	25	14	11
2-----	0	0	0	0
4-----	0	0	0	0
Hours held at 20°:				
½-----	100	100	96	11
1-----	96	80	94	22
2-----	40	42	40	11
4-----	13	11	7	5